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Gibson et al.

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(54) **LUMINESCENT PIXEL ASSEMBLY**

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PCT Pub. Date: **Apr. 12, 2012**

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(51) **Int. Cl.**

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G09G 3/19	(2006.01)
G02F 1/133	(2006.01)
G02F 1/167	(2006.01)

(52) **U.S. Cl.**
CPC ***G02F 1/167*** (2013.01); *G02F 2001/1678* (2013.01); *G02F 2202/046* (2013.01)

(58) **Field of Classification Search**
CPC .. G02B 26/0841; G02B 26/001; G03G 13/22; G03G 17/04; G09G 3/16; G02F 1/163; G02F 1/167; G02F 1/1393; G02F 1/136213; G02F 3/00; G02F 2203/50
USPC 359/245, 315, 247, 251–252, 254, 108, 359/237–238, 278–279, 290–292, 298, 359/300–302, 296, 259; 430/31–32; 345/49, 105, 107; 349/33, 38
See application file for complete search history.

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(57) **ABSTRACT**

An assembly corresponding to a pixel includes sub-assemblies that each correspond to a sub-pixel of the pixel. At least one of the sub-assemblies includes a luminescent fluid, black particles and a mirror. The luminescent fluid converts wavelengths of light less than a conversion wavelength of the sub-assembly to the conversion wavelength. The black particles are positionable within luminescent fluid in accordance with a color to be displayed by the assembly. The mirror is disposed at a bottom end of the sub-assembly.

15 Claims, 4 Drawing Sheets

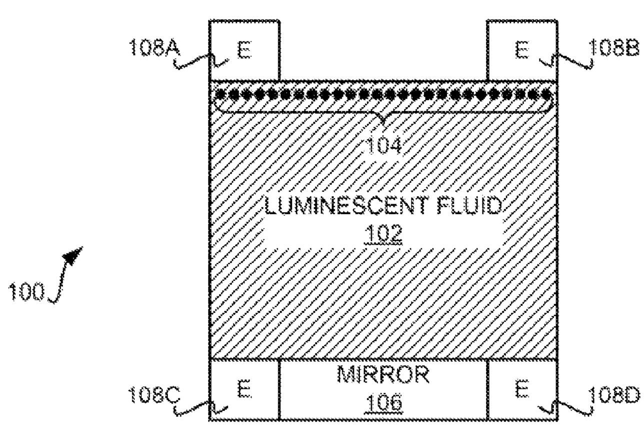

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FIG 1

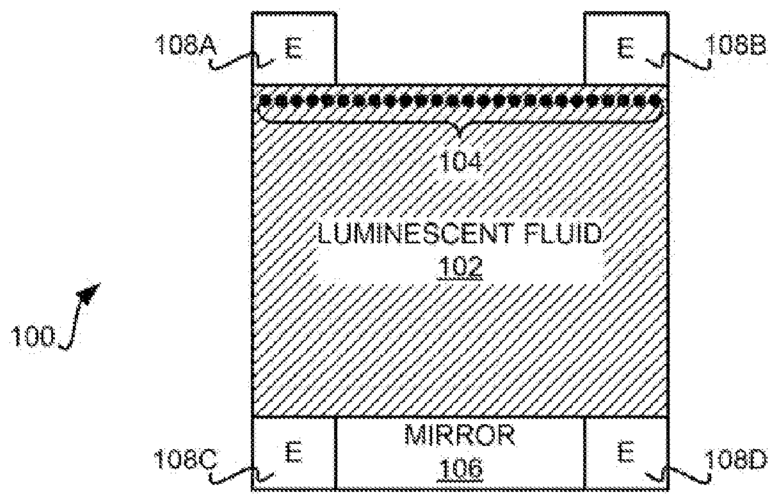


FIG 2A

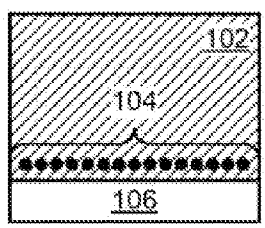


FIG 2B

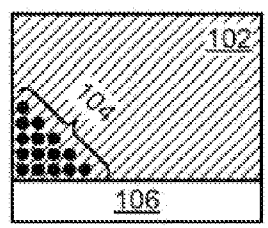


FIG 2C

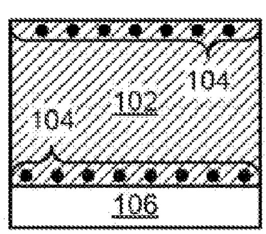


FIG 2D

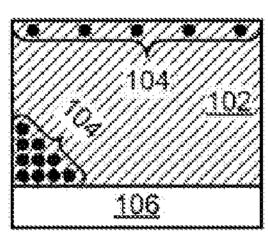


FIG 3

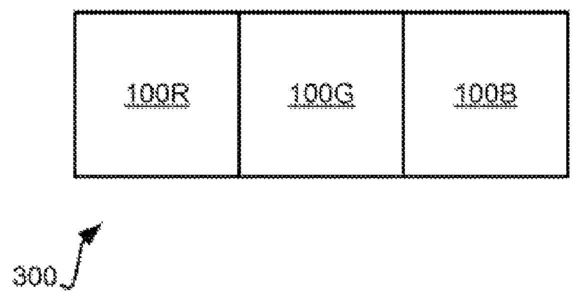

100R
100G
100B
300

FIG 4

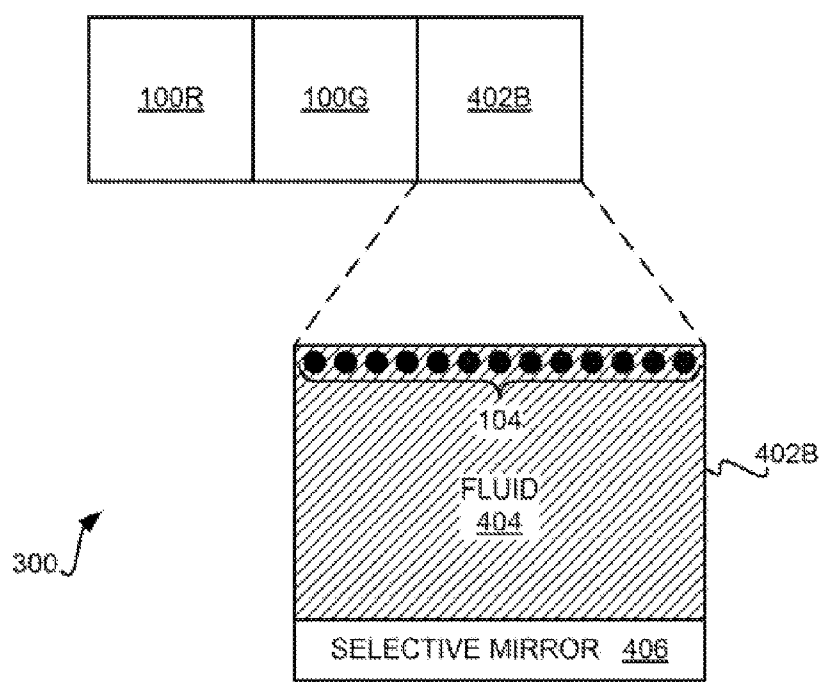

100R
100G
402B
104
402B
FLUID
404
SELECTIVE MIRROR 406
300

FIG 5

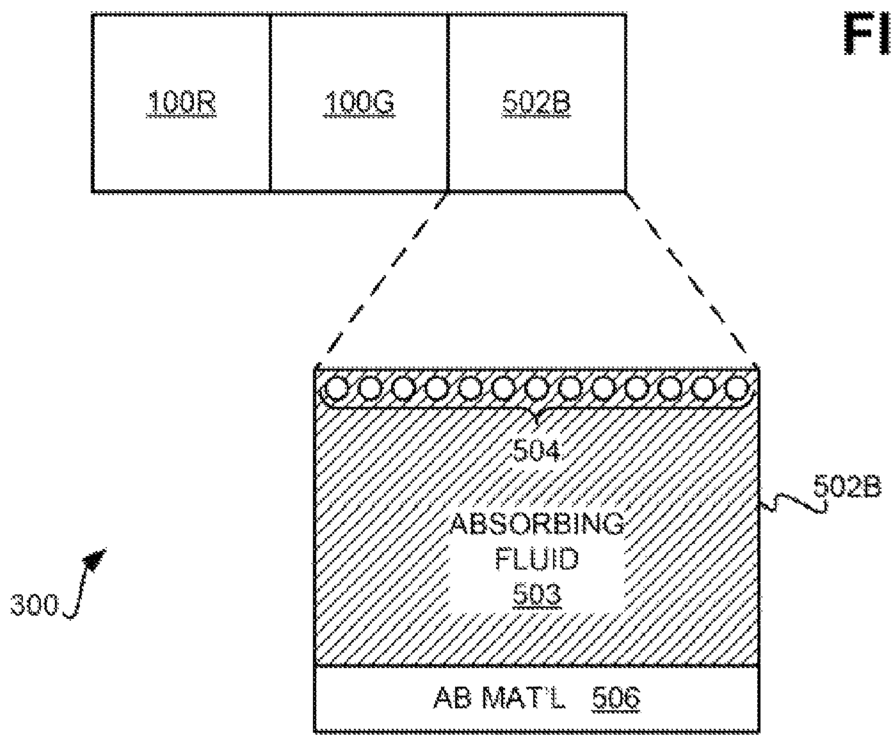


FIG 6

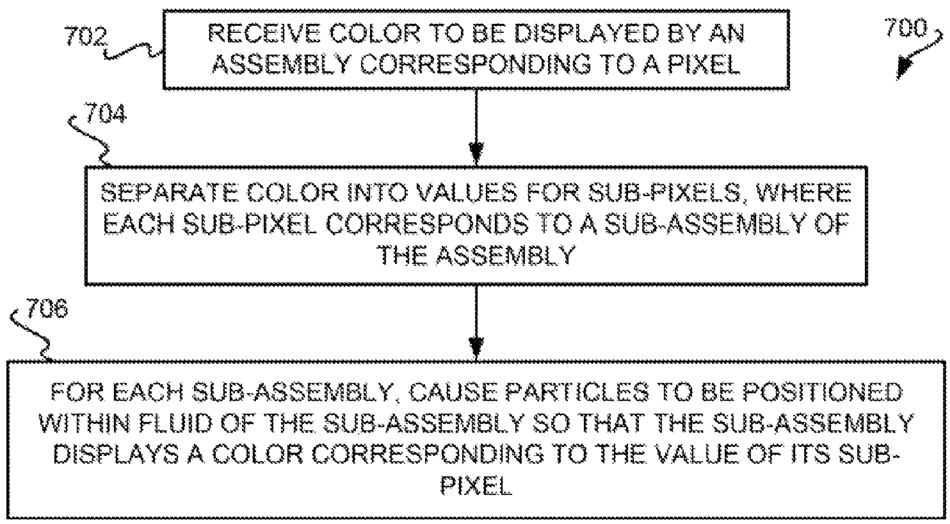
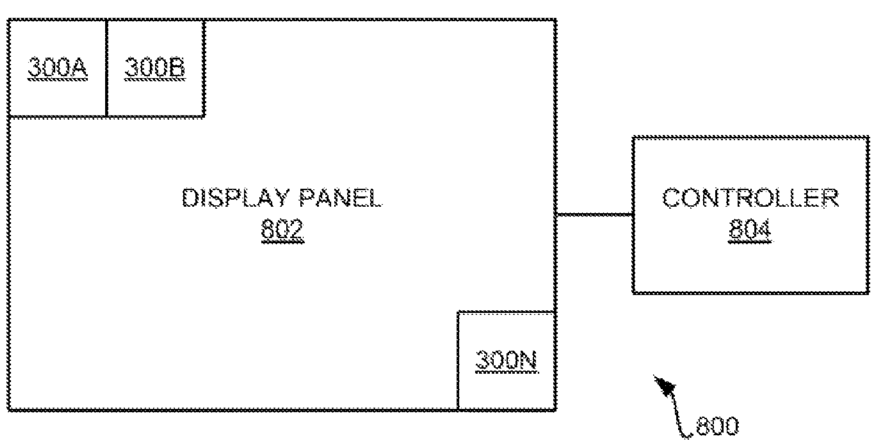

702
RECEIVE COLOR TO BE DISPLAYED BY AN ASSEMBLY CORRESPONDING TO A PIXEL
700
704
SEPARATE COLOR INTO VALUES FOR SUB-PIXELS, WHERE EACH SUB-PIXEL CORRESPONDS TO A SUB-ASSEMBLY OF THE ASSEMBLY
706
FOR EACH SUB-ASSEMBLY, CAUSE PARTICLES TO BE POSITIONED WITHIN FLUID OF THE SUB-ASSEMBLY SO THAT THE SUB-ASSEMBLY DISPLAYS A COLOR CORRESPONDING TO THE VALUE OF ITS SUB-PIXEL

FIG 7


300A
300B
DISPLAY PANEL
802
CONTROLLER
804
300N
800

LUMINESCENT PIXEL ASSEMBLY

CROSS-REFERENCE TO RELATED APPLICATION

This application is a U.S. National Stage Application of and claims priority to International Patent Application No. PCT/US2010/051244, filed on Oct. 3, 2010, and entitled "LUMINESCENT PIXEL ASSEMBLY."

BACKGROUND

Display devices traditionally operate by refreshing the displayed image a number of times per second, such as sixty times per second. When power is removed from such a display device, the display device no longer displays an image. Examples of these types of display devices include cathode-ray tube (CRT) display devices, as well as flat-panel display devices that employ plasma, light-emitting diode (LED), and/or some types of liquid crystal display (LCD) technologies.

More recently a type of display device has been introduced in which an image remains displayed even when power is removed from the display device. Power is utilized in such so-called bistable or multistable display devices primarily when the state of the image being displayed has to be changed. This type of display device uses less power than conventional display devices. Currently, this type of display device is most commonly used for electronic book reader ("e-reader") devices available from a number of different manufacturers.

Displays can be broadly categorized as either emissive or reflective. Emissive display devises have their own light sources, which emit light and thus can be used even in low ambient light conditions. Reflective display devices do not require their own light sources, but instead rely on the modulated reflection of ambient light, although in some cases reflective displays are provided with an auxiliary light source for viewing in low ambient light conditions. Reflective display devices typically use less power than emissive display devices because they do not need to provide their own light and because they are often multistable; that is, the image remains even when power is removed from such a display device. Although emissive display devices are more easily viewed in low ambient light conditions, reflective displays provide better viewing in bright outdoor lighting where stray reflections often overwhelm the relatively weak light source of emissive displays.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagram of a sub-assembly corresponding to a sub-pixel of a pixel, according to an embodiment of the disclosure.

FIGS. **2**A, **2**B, **2**C and **2**D are diagrams of the sub-assembly of FIG. **1** in which particles are in various positions, according to different embodiments of the disclosure.

FIGS. **3**, **4**, and **5** are each a diagram of an assembly corresponding to a pixel and that includes sub-assemblies corresponding to sub-pixels of this pixel, according to different embodiments of the disclosure.

FIG. **6** is a flowchart of a method of use, according to an embodiment of the disclosure.

FIG. **7** is a diagram of a rudimentary display device, according to an embodiment of the disclosure.

DETAILED DESCRIPTION

As noted in the background section, reflective displays can be used without an internal light source and are often multistable, thus requiring less power than an emissive display. Currently most reflective display devices can only display monochrome or grayscale images, and not full-color images. Such reflective display devices that can display color images are thus far suboptimal, in that they do not display the full gamut of color, and/or display dim color images that appear washed out.

By comparison, the disclosed reflective display device displays a full-color image that is more optimal. The reflective display device disclosed herein can display images with a wider, brighter color gamut than existing display devices. As such, the disclosed reflective display device is advantageous as compared to existing display devices.

FIG. **1** shows a luminescent sub-pixel sub-assembly **100**, according to an embodiment of the disclosure. The sub-assembly **100** corresponds to a sub-pixel of a pixel. For example, the sub-assembly **100** can correspond to a red sub-pixel, a green sub-pixel, or a blue sub-pixel to display the red, green, or blue part (or component) of the pixel. Light, including visible (white) light, enters the sub-assembly **100** at its top end.

The sub-assembly **100** includes a luminescent fluid **102** within which black particles **104** are positionable. There is a mirror **106** disposed at the bottom end of the sub-assembly **100**. In the embodiment of FIG. **1**, the black particles **104** are positionable within the luminescent fluid **102** responsive to an electric field generated within the fluid **102** by electrodes **108**A, **108**B, **108**C, and/or **108**D, which are collectively referred to as the electrodes **108**.

The embodiment depicted in FIG. **1** with respect to the electrodes **108** is provided as an example, and does not limit other configurations in which such electrodes **108** may be arranged. For instance, in another embodiment the electrodes **108**A and **108**B can be replaced by a single transparent electrode that extends across the top of the sub-pixel **100**. In general, there are at least two electrodes **108**. In the embodiment of FIG. **1**, the electrodes **108**A and **108**B are located at the top end of the luminescent fluid **102** and are separated from one another by a gap. Similarly, the electrodes **108**C and **108**D are located at the bottom end of the luminescent fluid **102** and are separated from one another by the mirror **106**, which can be an insulating mirror. Examples of insulating mirrors include mirrors made from titanium dioxide, barium sulfate, and polytetrafluoroethylene. The electrodes **108**C and **108**D may also be reflective.

In at least some embodiments, once the black particles **104** have been positioned within the luminescent fluid **102** as desired, power can be removed from the electrodes **108** such that the particles **104** remain in their current position within the fluid **102**. For example, the particles **104** may stick to the walls or the electrodes **108**. As another example, the time it takes for the particles **104** to diffuse back within the luminescent fluid **102** may be relatively long compared to the length of time that it is desired for the image to remain stable. It is noted that the sub-assembly **100** does not require a light source to be viewable, but rather can rely upon ambient light in this respect. As such, the sub-assembly **100** can be part of a reflective display device in some embodiments.

The luminescent fluid **102** has an absorption edge wavelength such that most wavelengths of light shorter than the absorption edge wavelength are converted to an emission wavelength band that is somewhat longer than the absorption edge wavelength. The gap between the absorption edge wavelength and the emission wavelength band is referred to as the Stokes' shift of the luminescent fluid **102**. In this respect, the luminescent fluid **102** may be or include luminophores having this emission wavelength band and this absorption edge wavelength. The luminophores may be luminescent dye molecules, polymers, oligomers, inorganic phosphor materials, or combinations of these materials. It is noted that the absorption edge wavelength of the luminescent fluid **102** is also referred to as a conversion wavelength.

The luminophores may be contained with small particles that are suspended within the fluid **102**. Such particles may include transparent resins, polymers, and/or binders in which the luminophores are contained. To absorb ambient light over a desired broad spectrum, multiple luminophores that absorb different wavelength ranges may be employed. To tailor the final emission spectrum resulting from these luminophores, a series of luminophores may be used where the emission band of one luminophore overlaps with the absorption band of another luminophore. This overlap facilitates energy transfer from higher energy luminophores to lower energy luminophores through processes such as Förster exchange. For example, the luminophores can be a series of organic dyes, which are sometimes referred to as relay dyes, and which transfer their absorbed energy to a final emissive dye.

In another embodiment, a set of luminophores can be utilized that together absorb the desired wavelength band but have different Stokes' shifts such that their emission bands are approximately the same and which all directly contribute to emitting the desired color. For example, luminophores capable of emitting in desired wavelength bands within the red or green portions of the visible spectrum include perylene, coumarin, pyromethene, or rhodamine dyes. Such organic dyes can also be used as the absorbers, or sensitizers, in a series of relay dyes, as can various luminescent polymers, oligomers, inorganic phosphors, or quantum dots. Where a sensitizer is used, the sensitizer absorbs predetermined wavelengths of light and transfers the energy resulting from this absorption to luminophores.

It is noted that the absorption edge wavelength of the luminescent fluid **102** is shorter than the wavelengths within the emission wavelength band of the fluid **102**, in at least some embodiments. Most desirably, the luminescent fluid **102** absorbs all the shorter wavelengths of the available light. In some embodiments, such wavelengths can include near-ultraviolet light.

The black particles **104** may be based on carbon black or inorganic black pigments. The black particles **104** absorb at least visible (white) light. The black particles **104** are electrophoretically charged given a non-zero zeta potential, via techniques known within colloidal science. The black particles **104** are thus positioned within the luminescent fluid **102**, using the electric fields created by electrodes **108** in the embodiment of FIG. **1**, such that the sub-assembly **100** displays the desired intensity of its corresponding color.

For example, the sub-assembly **100** may correspond to a red, green, or blue sub-pixel of a pixel, although the sub-assembly **100** is exemplarily described in relation to the case where it corresponds to a red sub-pixel. Therefore, if this red sub-pixel is to display a minimum value of red (i.e., no red), then the electrodes may have power applied to them such that an electric field is generated within the luminescent fluid **102** to cause the black particles **104** to be positioned at the top end of the sub-assembly **100**, as depicted in FIG. **1**. The black particles **104** absorb wavelengths of at least visible light, and thus do not permit light to reach the luminescent fluid **102**. As such, in this case, the sub-assembly **100** outputs negligible light.

By comparison, if the red sub-pixel is to display a maximum value of red, then the electrodes **108** may have power applied to them such that an electric field is generated within the luminescent fluid **102** to cause the black particles **104** to be positioned at the bottom end of the sub-assembly **100**, against the mirror **106**. This case is depicted in FIG. **2**A. Alternatively, the electrodes **108** may have power applied to them such that an electric field is generated within the luminescent fluid **102** to cause the black particles **104** to be positioned at a bottom corner of the sub-assembly **100**. This case is depicted in FIG. **2**B. It is noted that in FIGS. **2**A and **2**B, as well as in FIGS. **2**C and **2**D, the electrodes **108** have been omitted from illustrative convenience, and the mirror **106** extended across the width of the bottom of the luminescent fluid **102**.

In both the cases of FIGS. **2**A and **2**B, light incident to the top end of the sub-assembly **100** reaches the luminescent fluid **102**. The luminescent fluid **104** converts the wavelengths shorter than the absorption edge wavelength of the luminescent fluid to the red emission wavelength band of the luminescent fluid. The sub-assembly **100** outputs maximum red light, because the black particles **104** are not preventing any light from reaching the fluid **102**.

In at least some situations, the configuration of FIG. **2**B may be more desirable to use to produce red than the configuration of FIG. **2**A. This is because some of the luminescent light in FIG. **2**A is emitted downwards, whereas it is more desirable to have this light reflected upwards, as in FIG. **2**B. In one embodiment, the mirror **106** in FIG. **2**B can be a broadband mirror, particularly where the optical density of the luminescent fluid **102** is high enough to absorb wavelengths of light shorter than red before the wavelengths are reflected back out of the fluid **102**. Where the embodiment of FIG. **2**B is used to implement a green sub-pixel, the mirror **106** reflects green light, and may also reflect blue light, but should not reflect red light.

Furthermore, the red sub-pixel may display a value of red between the minimum and the maximum values of red. As such, the electrodes **108**A and **108**B may have power applied to them such that an electric field is generated within the luminescent fluid **102** to cause some black particles **104** to be positioned at the bottom end of the sub-assembly **100**, and other black particles **104** to be positioned at the top end of the sub-assembly **100**. Thus case is depicted in FIG. **2**C. Alternatively, the electrodes **108**A, **108**B, **108**C, and **108**D may have power applied to them such that an electric field is generated within the luminescent fluid **102** to cause some black particles **104** to be positioned at the bottom left or right corner of the sub-assembly **100**, and other black particles **104** to be positioned at the top end of the sub-assembly **100**. This case is depicted in FIG. **2**D.

In both the cases of FIGS. **2**C and **2**D, just some of the light incident to the top end of the sub-assembly **100** reaches the luminescent fluid **102**. The luminescent fluid **102** converts the wavelengths shorter than the absorption edge wavelength of the luminescent fluid **102** to the red emission wavelength band of the luminescent fluid **102**. The sub-assembly **100** outputs less-than-maximum red light, because the black particles **104** at the top end of the sub-assembly **100** prevent some ambient light from reaching the luminescent fluid **102** and absorb some of the luminescent red light that is created by ambient light that does reach the luminescent fluid **102**.

FIG. **3** shows a luminescent pixel assembly **300**, according to an embodiment of the disclosure. The pixel assembly **300** includes three sub-assemblies **100**R, **100**G, and **100**B, collectively referred is as the sub-assemblies **100**. The pixel assembly **300** corresponds to a full-color pixel, and the sub-assemblies **100** correspond to the sub-pixels of this pixel. Each sub-assembly **100** corresponds to a different color sub-pixel of the pixel of the assembly **300**. The sub-assembly **100**R corresponds to the red sub-pixel and is referred to as the red sub-assembly **100**R; the sub-assembly **100**G corresponds to the green sub-pixel and is referred to as the green sub-assembly **100**G; and, the sub-assembly **100**B corresponds to the blue sub-pixel and is referred to as the blue sub-assembly **100**B.

Each sub-assembly **100** of FIG. **3** is implemented in accordance with FIG. **1**. The emission wavelength band of the red sub-assembly **100**R is in the red portion of the visible spectrum. The emission wavelength band of the green sub-assembly **100**G lies in the green portion of the visible spectrum. The emission wavelength band of the blue sub-assembly **100**B is in the blue portion of the visible spectrum.

In the case of the red sub-pixel, the mirror **106** of FIG. **1** disposed at the bottom end of the sub-assembly **100**R can be a broadband mirror that reflects wavelengths of at least visible (white) light, or a wavelength-selective mirror reflecting just red wavelengths of light. In the case of the green sub-pixel, the mirror **106** of the green sub-assembly **100**G may not reflect wavelengths of red light that do not contribute to the desired color for that sub-pixel; that is, the mirror **106** in this case is a wavelength-selective mirror reflecting just green and blue wavelengths of light. The fluid **102** in the green sub-pixel does not absorb these red wavelengths in this case so the red wavelengths would be returned to viewer if the mirror **106** did reflect them. In the case of the blue sub-pixel, the mirror **106** of the blue sub-assembly **100**B may not reflect red or green wavelengths that do not contribute to the desired color for that sub-pixel; that is, the mirror **106** in this case is a wavelength-selective mirror reflecting just blue wavelengths of light.

In other embodiments, a blue sub-pixel **100** may include a mirror **106** that is a blue-reflecting mirror, but a transparent fluid rather than a blue-emitting luminescent fluid. This is because there is less available light at the short wavelengths available for harvesting by a blue luminescent fluid. Luminescence may, however, be employed for the blue sub-pixel depending on how high the internal emission efficiency of the blue luminophores is, and how efficiently the emitted light can be protected or coupled out of the corresponding sub-assembly **100**.

The black particles **104** of FIG. **1** within each sub-assembly **100** of FIG. **3** are positioned within the luminescent fluid **102** of FIG. **1** within each sub-assembly **100** of FIG. **3** in accordance with the color to be displayed by the sub-assembly **300** itself. A color has a color value that in one embodiment is separable into a red value, a green value, and a blue value. The red value is provided by the red sub-pixel to which the sub-assembly **100**R corresponds; the green value is provided by the green sub-pixel to which the sub-assembly **100**G corresponds; and, the blue value is provided by the blue sub-pixel to which the sub-assembly **100**B corresponds.

In other embodiments, however, the color value may be separable into values in addition to or in lieu of a red value, a green value, and a blue value. For example, the color value may be separable into a red value, a green value, a blue value, and a white value. As another example, the color value may be separable into a cyan value, a magenta value, a yellow value, and a white value. It is noted that any sub-pixel can provide black by simply being turned off.

The black particles **104** of the red sub-assembly **100**R are thus positioned within the luminescent fluid **102** in accordance with the red value of the desired color, as has been described in relation to FIGS. **1** and **2**A-**2**D. The black particles **104** of the green sub-assembly **100**G are positioned within the luminescent fluid **102** in accordance with the green value of the desired color, in the same manner as has been described in relation to FIGS. **1** and **2**A-**2**D. The black particles **104** of the blue sub-assembly **100**B are positioned within the luminescent fluid **102** in accordance with the blue value of the desired color, also in the same manner as has been described above in relation to FIGS. **1** and **2**A-**2**D.

As has been described above, each sub-assembly **100** converts wavelengths of light shorter than an absorption edge wavelength to the emission band wavelengths. The red emission band wavelengths are longer than the green emission band wavelengths, which are longer than the blue emission band wavelengths. Therefore, the red sub-assembly **100**R converts more ambient light than the green sub-assembly **100**G and the blue sub-assembly **100**B do. For example, the blue sub-assembly **100**B converts just ultraviolet and deep blue light, which has a shorter wavelength than the blue emission band light, and does not convert red and green light, which have longer wavelengths than blue light. As such, the amount of red light (i.e., the power of the red light) that can be maximally output by the red sub-assembly **100**R is greater than the amount of green light that can be maximally output by the green sub-assembly **100**G, which is greater than the amount of blue light that can be maximally output by the blue sub-assembly **100**B.

To compensate for this, in one embodiment the sub-assemblies **100** of FIG. **3** may have different sizes so that when each sub-assembly **100** has its black particles **104** positioned as depicted in FIG. **2**A or **2**B, equal amounts of red, green, and blue light are output so that white light is output by the assembly **300** as a whole. In this embodiment the red sub-assembly **100**R may be smaller in size than the green sub-assembly **100**G. Likewise, the green sub-assembly **100**G may be smaller in size than the blue sub-assembly **100**B. Furthermore, this issue is compensated for as to the green sub-assembly **100**G due to the fact that wavelengths to which the human visual system (HVS) is less sensitive are converted to wavelengths to which the HVS is more sensitive. This effect also helps compensate for this issue as to the blue sub-assembly **100**B, but to a lesser extent.

In other embodiments, however, in addition to and/or in lieu of having differently sized sub-assemblies **100** within a given assembly **300** corresponding to a pixel, the green sub-assembly **100**G and/or the blue sub-assembly **100**B may be substituted with a different type of sub-assembly. FIGS. **4**, **5**, and **6** show different assemblies **300** that include the red sub-assembly **100**R implemented as in FIGS. **1** and **3**, but that include different types of blue and/or green sub-assemblies as compared to FIG. **3**, according to varying embodiments of the disclosure. Particularly, FIGS. **4** and **5** show different assemblies **300** that include different types of blue sub-assemblies **402**B and **502**B, respectively.

In FIG. **4**, the assembly **300** includes the red sub-assembly **100**R and the green sub-assembly **100**G no differently than the embodiment of FIG. **3**. However, the blue sub-assembly **100**B has been replaced by the blue sub-assembly **402**B. As depicted in FIG. **4**, the blue sub-assembly **402**B includes black particles **104** no differently than the sub-assembly **100** of FIG. **1**. The blue sub-assembly **402**B also includes fluid **404**. In one embodiment, the fluid **404** is luminescent fluid that has an emission wavelength band that provides a blue color, no differently than the embodiment of FIG. **1**. However, in another embodiment, the fluid **404** is a non-luminescent, transparent fluid. Furthermore, the blue sub-assembly **402**B of FIG. **4** can include the electrodes **108** of FIG. **1** in one embodiment, which are not shown in FIG. **4** for illustrative clarity and convenience.

The blue sub-assembly **402**B of FIG. **4** includes a wavelength-selective mirror **406**. The wavelength-selective mirror **406** of the blue sub-assembly **402**B reflects just blue wavelengths of light, and may also reflect near ultraviolet light if the near ultraviolet light is being utilized by a fluid **404** that is luminescent, and the near ultraviolet light is not absorbed by the mirror **406**. The mirror **406** is further used in the blue sub-assembly **402**B with a fluid **404** that is not luminescent (i.e., that is transparent) in one embodiment if the internal emission efficiency of the blue luminophores cannot be made adequately high, or the projection or out-coupling of the blue luminescence is not sufficiently efficient. Such efficiencies are of particular concern for the blue sub-pixel, because a smaller fraction of available ambient light is generally absorbed by the luminescent fluid **404**, particularly just deep blue light and/or near-ultraviolet light.

In FIG. **4**, the red sub-assembly **100**R can include a mirror **106** that reflects all wavelengths of at least visible (white) light if the non-red wavelengths are absorbed by the luminescent fluid **102** of the sub-assembly **100**R within two passes through the fluid **102**. However, if the luminescent fluid **102** absorbs most of the wavelengths during their first pass through the fluid **102**, then the mirror **106** of the red sub-assembly **100**R does not have to reflect all such wavelengths, in which case it can be sufficient for the mirror **106** to reflect just the red light not absorbed by the fluid **102**. Similarly, the mirror **106** of the green sub-assembly **100**G can reflect all wavelengths except for red wavelengths of light—i.e., it can reflect green and blue wavelengths of light.

In FIG. **5**, the assembly **300** includes the red sub-assembly **100**R and the green sub-assembly **100**G no differently than the embodiment of FIG. **3**. However, the blue sub-assembly **100**B has been replaced by the blue sub-assembly **502**B. As depicted in FIG. **5**, the blue sub-assembly **502**B includes white particles **504** instead of black particles **104** as in FIG. **1**. The white particles **504** reflect wavelengths of at least visible (white) light, as opposed to absorbing such wavelengths as the black particles **104** do. The white particles **504** may be titanium dioxide or other materials having a high index of refraction in the visible band of light. The blue sub-assembly **502**B further includes an absorbing material **506** in lieu of a mirror **106** as in FIG. **1**. The absorbing material **506** absorbs wavelengths of at least visible (white) light, and may be carbon black, a broadly absorbing inorganic black pigment, a broadly absorbing photonic structure, or some combination of these materials.

The blue sub-assembly **502**B of FIG. **5** also includes absorbing fluid **503** instead of luminescent fluid **102** as in FIG. **1**. The absorbing fluid **503** has a defined wavelength range, and may be an organic solvent containing one or more optically absorbing organic dyes or pigments. The fluid **503** thus absorbs wavelengths of at least visible (white) light that are outside the defined wavelength range. The defined wavelength range corresponds to blue wavelengths of light. The blue sub-assembly **502**B of FIG. **5** can also include the electrodes **108** of FIG. **1** in one embodiment, which are not shown in FIG. **5** for illustrative clarity and convenience.

The white particles **504** of the blue sub-assembly **502**B of FIG. **5** are positionable within the fluid **503** in a similar manner to how the black particles **104** of the sub-assembly **100** of FIG. **1** are positionable within the fluid **102**, as has been described in relation to FIGS. **1** and **2**A-**2**D. The white particles **504** of the blue sub-assembly **502**B are positioned within the fluid **503** in accordance with the color to be displayed by the sub-assembly **300** itself. For a given blue value, the white particles **504** are positioned somewhat differently, however, than the black particles **104** of the blue sub-assembly **100**B of FIG. **3** are.

Specifically, when the blue sub-assembly **502**B is to output maximum white light, the white particles **504** are positioned at the top side of the sub-assembly **502**B, as depicted in FIG. **5**. When the blue sub-assembly **502**B is to output maximum value of blue light, the white particles **504** are positioned at the bottom side of the sub-assembly **502**B, similar to as in FIG. **2**A. When the blue sub-assembly **502**B is to output no light (i.e., corresponding to the color black), the white particles **504** are positioned at the bottom left or right corner of the sub-assembly **502**B, similar to as in FIG. **2**B. When the blue sub-assembly **502**B is to output a level of blue light less than the maximum value, some white particles **504** are positioned at the top side of the sub-assembly **502**B, and other white particles **504** are not, similar to as in FIG. **2**C or FIG. **2**D.

The embodiment of FIG. **5** helps equalize the maximum amount of blue light that the blue sub-assembly **502**B can output as compared to the maximum amounts of red and green light that the red and green sub-assemblies **100**R and **100**G can output. This is accomplished by the white particles **504** reflecting the blue light that is not absorbed by the absorbing fluid **503**. That is, when visible (white) light is incident to the top side of the blue sub-assembly **502**B and at least some white particles **504** are not at the top side of the sub-assembly **502**B, the fluid **503** absorbs non-blue wavelengths of this light, and the remaining blue light is reflected by the white particles **504**.

In this respect, it is noted that when the white particles **504** are spread across the bottom of the blue sub-assembly **502**B, they act as a broadband mirror. As such, no more blue light is returned per unit area than if such a mirror were used. By comparison, when the white particles **504** are spread across the top side of the blue sub-assembly **502**B, all the visible wavelengths of light are returned, which helps to boost the brightness of a white state. Because red and green wavelengths are also reflected, the red and green sub-assemblies **502**R and **502**G can be made smaller, to leave more room for the blue sub-assembly **502**B, which in this case can also be referred to as a blue-white sub-assembly. By having such a blue-white sub-assembly **502**B in this case, a color gamut appropriate for a given display application can be more easily engineered.

FIG. **6** shows a method of use **700** of an assembly corresponding to a pixel, where the assembly has sub-assemblies corresponding to sub-pixels of this pixel, according to an embodiment of the disclosure. The method **700** receives a color to be displayed by the assembly (**702**). The color is separated into values for the sub-pixels of the pixel (**704**). For example, a color of the pixel may be defined as values for red, green, and blue parts (or components) of the red, green, and blue sub-pixels, respectively, of the pixel.

For each sub-assembly, the method **700** causes the particles of the sub-assembly to be positioned within the fluid of the sub-assembly so that the sub-assembly displays a color corresponding to the value of its sub-pixel (**706**). For example, the sub-assembly corresponding to the red sub-pixel displays an intensity of the color red corresponding to the value of the red sub-pixel. Likewise, the green sub-assembly displays an intensity of the color green corresponding to the value of the green sub-pixel, and the blue sub-assembly displays an intensity of the color blue corresponding to the blue sub-pixel.

Specifically, in the case where a given sub-assembly is implemented as the sub-assembly **100** of FIG. **1**, the black particles **104** are positioned within the luminescent fluid **102**, via generation of an appropriate electric field by the electrodes **108**, so that the proper intensity of the color to which the sub-assembly corresponds is displayed. Each such sub-assembly **100** displays the proper intensity of its corresponding color via the interaction of light with the luminescent fluid **102**, the black particles **104**, and the mirror **106** disposed at the bottom end of the sub-assembly **100**. The luminescent fluid **102** converts wavelengths of light shorter than its absorption edge wavelength to the emission wavelength band, as has been described.

In conclusion, FIG. **7** shows a rudimentary display device **800**, according to an embodiment of the disclosure. The display device **800** includes a display panel **802** and a controller **804**. The display panel **802** is made up of a number of assemblies **300**A, **300**B, . . . , **300**N, collectively referred to as the assemblies **300**, and which correspond to a number of pixels of the display panel **802**. For example, for a display panel **802** having a resolution of X-by-Y pixels, there are X-times-Y assemblies **300**.

Each assembly **300** can be implemented as has been described in relation to FIG. **3**, **4**, **5**, or **6**. As such, each assembly **300** includes a number of sub-assembles, as has been described. Where each assembly **300** includes red, green, and blue sub-assemblies, this means that there are a total of three-times-X-times-Y sub-assemblies within the display panel **802**.

The controller **804** is implemented at least in hardware, such as via one or more integrated circuits (IC's). The controller **804** appropriately controls the sub-assemblies of the assemblies **300** so that the assemblies **300** each display the color of a corresponding pixel of a desired image received by the controller **804**. For instance, where the sub-assemblies include electrodes, such as the electrodes **108** of FIG. **1**, the controller **804** appropriately causes the electrodes **108** to generate an electric field so that the assemblies **300** display the proper colors.

The controller **804** may receive the image from a competing device, or another type of electronic device, such as an optical disc player, a cable television box, a satellite television box, and so on. The controller **804** may further receive the image from a memory that is internal or external to the display device **800** itself. For example, data representing an electronic book may be communicated to the controller **804**, over a network, and from a memory card inserted into the display device **800**. The controller **804** renders the text of a page of the book, and causes the assemblies **300** to appropriately display the page.

As has been noted above, in at least some embodiments, once the particles of the sub-assemblies of the assemblies **300** have been positioned within the fluid in accordance with particular colors to be displayed, power may be removed from the assemblies **300** such that the assembles **300** still display these colors. That is, the assemblies **300** do not have to be continually refreshed to display a desired image. As such, the display device **800** typically consumes less power than a display device that has to refresh the displayed image a number of times per second using electricity, because the assemblies **300** consume power just when their corresponding image parts change.

Finally, although embodiments have been described herein that pertain to a full-color display—i.e., in relation to an assembly that has sub-assemblies corresponding to different color parts or components of the color of a pixel—other embodiments can be implemented that pertain to a black-and-white or a grayscale display. In such an embodiment, an assembly may have as few as one sub-assembly, but may have more than one sub-assembly, which each correspond to the color black. One sub-assembly may be employed where different intensities of gray can be displayed by the single sub-assembly, or where just a black-and-white display is desired. More than one sub-assembly may be employed where a grayscale display is desired but where a given sub-assembly can just display black or can just display white. Furthermore, embodiments can include more than three sub-assemblies per pixel. As one example, a pixel may encompass a red sub-assembly, a green sub-assembly, a blue sob-assembly, as well as a white sub-assembly.

We claim:

1. An assembly corresponding to a pixel, comprising:

a plurality of sub-assemblies, each sub-assembly corresponding to a sub-pixel of the pixel,

where at least a first of the sub-assemblies comprises:

a luminescent fluid to convert wavelengths of light less than a conversion wavelength of the sub-assembly to the conversion wavelength; and

a plurality of black particles positionable within the luminescent fluid in accordance with a color to be displayed by the assembly; and

where at least a second of the sub-assemblies comprises:

an absorbing fluid to absorb wavelengths of light outside a defined wavelength range;

a plurality of white particles positionable within the absorbing fluid in accordance with a color to be displayed by the assembly, wherein, when the white particles are:

positioned towards a top end of the second sub-assembly, a number of wavelengths of visible light that reach the absorbing fluid is minimized and a greater amount of the visible light is emitted;

positioned towards a bottom end of the second sub-assembly, the number of wavelengths of the visible light that reach the absorbing fluid is maximized and wavelengths within the defined wavelength range are emitted; and

an absorbing material disposed at a bottom end of the second sub-assembly.

2. The assembly of claim **1**, wherein the visible light is absorbed by the absorbing material at the bottom end of the second sub-assembly after it enters through the top end of the sub-assembly and exits through the top end of the second sub-assembly.

3. The assembly of claim **1**, wherein the luminescent fluid comprises one or more of:

a luminophore having the conversion wavelength;

a sensitizer to absorb predetermined wavelengths and to transfer energy resulting from absorption of the predetermined wavelengths to the luminophore.

4. The assembly of claim **1**, wherein the black particles of the first sub-assembly is positionable within the luminescent fluid responsive to an electric fluid generated within the luminescent fluid, and the second of the sub-assemblies further comprises:

a plurality of electrodes to generate the electric field in accordance with the color to be displayed by the assembly.

5. The assembly of claim **1**, wherein the sub-assemblies comprise:

the first sub-assembly corresponding to a red sub-pixel of the pixel, the conversion wavelength of the first sub-assembly being a red wavelength;

the second sub-assembly corresponding to a blue sub-pixel of the pixel, the conversion wavelength of the second sub-assembly being a blue wavelength; and,

a third sub-assembly corresponding to a green sub-pixel of the pixel, the conversion wavelength of the third sub-assembly being a green wavelength.

6. The assembly of claim **5**, wherein a mirror disposed at the bottom of each of the first sub-assembly and the third sub-assembly is one of a broadband mirror and a wavelength-selective mirror.

7. A display device comprising:

a plurality of assemblies corresponding to pixels, each assembly comprising a plurality of sub-assemblies, each sub-assembly corresponding to a sub-pixel of the pixel to which the assembly corresponds,

where at least a first of the sub-assemblies comprises:

a luminescent fluid to convert wavelengths of light less than a conversion wavelength of the sub-assembly to the conversion wavelength;

a plurality of black particles positionable within the luminescent fluid in accordance with a color to be displayed by the assembly; and

a mirror disposed at a bottom end of the first sub-assembly; and

where at least a second of the sub-assemblies comprises:

an absorbing fluid to absorb wavelengths of light outside a defined wavelength range;

a plurality of white particles positionable within the absorbing fluid in accordance with a color to be displayed by the assembly, wherein, when the white particles are:

positioned towards a top end of the second sub-assembly, a number of wavelengths of visible light that reach the absorbing fluid is minimized and a greater amount of the visible light is emitted;

positioned towards a bottom end of the second sub-assembly, a number of wavelengths of the visible light that reach the absorbing fluid is maximized and wavelengths within the defined wavelength range are emitted; and

positioned towards a bottom side of the sub-assembly, a minimum amount of visible light is emitted; and

an absorbing material disposed at a bottom end of the second sub-assembly.

8. The display device of claim 7, wherein the sub-assemblies comprises one of:

the first sub-assembly corresponding to a red sub-pixel of the pixel, the conversion wavelength of the first sub-assembly being a red wavelength, and the mirror disposed at the bottom end of the first sub-assembly being a broadband mirror that is to reflect wavelengths of the visible light; and

a third sub-assembly corresponding to the red sub-pixel of the pixel, the conversion wavelength of the third sub-assembly being a red wavelength, and the mirror disposed at the bottom end of the third sub-assembly being a wavelength-selective mirror that reflects just red wavelengths of light.

9. The display device of claim 7, wherein the sub-assemblies comprises one of:

the first sub-assembly corresponding to the green sub-pixel of the pixel, the conversion wavelength of a third sub-assembly being a green wavelength, and the mirror disposed at the bottom end of the third sub-assembly being a wavelength-selective mirror that reflects just green wavelengths and blue wavelengths of light;

a fourth sub-assembly corresponding to the green sub-pixel of the pixel, the conversion wavelength of the fourth sub-assembly being the green wavelength, and the mirror disposed at the bottom end of the fourth sub-assembly being a wavelength-selective mirror that reflects just the green wavelengths of light.

10. The display device of claim 7, wherein the sub-assemblies comprises:

the second sub-assembly corresponding to a blue sub-pixel of the pixel, the defined wavelength of light of the second sub-assembly being a blue wavelength,

wherein the absorbing material disposed at the bottom end of the second sub-assembly is a wavelength-selective absorbing material that is to absorb wavelengths of light other than the blue wavelengths.

11. The display device of claim 7, wherein the sub-assemblies further comprise a sub-assembly corresponding to a blue sub-pixel of the pixel and comprising:

a transparent fluid;

a plurality of black particles positionable within the transparent fluid in accordance with the color to be displayed by the assembly, the black particles to absorb wavelengths of the visible light; and,

a wavelength-selective mirror disposed at a bottom end of the sub-assembly to reflect just blue wavelengths of the visible light.

12. The display device of claim 7, wherein the sub-assemblies further comprise a sub-assembly corresponding to a blue sub-pixel of the pixel and comprising:

the absorbing fluid that absorbs wavelengths of light that are outside the defined wavelength range, the defined wavelength range corresponding to blue wavelengths; and

the white particles that reflect wavelengths of the visible light.

13. A method comprising:

receiving a color to be displayed by an assembly corresponding to a pixel;

separating the color to be displayed by the assembly into values for sub-pixels, each sub-pixel corresponding to a sub-assembly of the assembly, where each sub-assembly of the assembly corresponds to a different sub-pixel of the pixel;

wherein for at least a first of the sub-assemblies:

causing a plurality of black particles to be positioned within a luminescent fluid of the first sub-assembly such that the first sub-assembly displays a color corresponding to the value for the sub-pixel to which the first sub-assembly corresponds, and

wherein at least the first of the sub-assemblies displays the color corresponding to the value for the sub-pixel to which the first sub-assembly corresponds via an interaction of light with the luminescent fluid, the black particles, and a mirror disposed at a bottom end of the first sub-assembly, where the luminescent fluid converts wavelengths of light less than a conversion wavelength of the first sub-assembly to the conversion wavelength; and

wherein for at least a second of the sub-assemblies:

causing a plurality of white particles to be positioned within an absorbing fluid of the second sub-assembly such that the second sub-assembly displays a color corresponding to the value for the sub-pixel to which the second sub-assembly corresponds; and

wherein at least the second of the sub-assemblies displays the color corresponding to the value for the sub-pixel to which the second sub-assembly corresponds via an interaction of light with the absorbing fluid, the white particles, and an absorbing material disposed at a bottom end of the second sub-assembly, where the absorbing fluid absorbs wavelengths of light other than a wavelength of light corresponding to the color associated with the second sub-assembly.

14. The method of claim 13, wherein, when the black particles are:

positioned towards a top end of the first sub-assembly, a number of wavelengths of visible light that reach the luminescent fluid is minimized; and positioned towards a bottom end of the first sub-assembly the number of wavelengths of the visible light that reach the luminescent fluid is maximized.

15. The method of claim **14**, wherein, when the white particles are:

positioned towards a top end of the second sub-assembly, a number of wavelengths of visible light that reach the absorbing fluid is minimized and a greater amount of the visible light is emitted;

positioned towards a bottom end of the second sub-assembly, the number of wavelengths of the visible light that reach the absorbing fluid is maximized and wavelengths within the defined wavelength range are emitted.

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